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Characteristic attributes of the peanut (*Arachis hypogaea* L.) for its separation

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Abstract. Physical and aerodynamic peanut (*Arachis hypogaea* L.) properties have been investigated and defined. The geometric diameter, mass, and standard deviation values of three peanut varieties (American, Chinese, and Egyptian) had no significant differences. The terminal velocity for different varieties of pods ranged between 7.7 to 12.9 m s^{-1}. Experimental measurements of shelled components of the Egyptian variety (Gisa-5) indicated that the terminal velocity value of 7.4 m s^{-1} was optimal for airflow velocity to separate shelled peanut components from the shells with only 1.8% loss of intactness and split seeds on a sieved surface of 6.3 and 8.0 mm. Also importantly, air velocity values of 10.2 and 9.8 m s^{-1} were found adequate to separate the intact seeds from the split seeds when they are sieved on surfaces with meshes of 8.0 and 6.3 mm, respectively.

Keywords: peanut, *Arachis hypogaea* L., terminal velocity, geometric diameter, vertical air stream, suction fan

INTRODUCTION

The peanut, also known as the groundnut, has become an important food and export crop in several countries, such as China, USA, Nigeria, Niger, and Egypt. It is the fifth most important oilseed crop in the world after soybean, cotton seed, rape seed, and sunflower seed (Nwokolo, 1996).

In agricultural engineering operations, such as those for machine development, air conveying and separation, it is essential to have an accurate understanding of the basic properties of the crop product. The separation processes for grain crops, the determination of the terminal velocity of many crops, and the evaluation of the physical and aerodynamic properties have been the subjects of study by numerous authors (Bezrutskin *et al.*, 1967; Gorial and O'Callaghan, 1991; Smith and Stroshine, 1995; Uhl and Lamp, 1966; Tado *et al.*, 1996; Kahrs, 1994; etc...). On the one hand, little work has been done concerning the aerodynamic characteristics of the peanut.

The separation of mixed components under an air stream is possible only when accurate air pressure is delivered and some of the components reach their terminal velocity (Bezrutskin *et al.*, 1967; Gorial and O'Callaghan, 1991). These authors concluded that the range of grains found in a normal harvest sample corresponds to a range of terminal velocities rather than a single characteristic velocity. The same authors reported the terminal velocity values of various grain crops such as rice, soybean, maize, rye groat, whole lentil, sorghum, mung, adzuki bean, buckwheat, pinto, marrowfat, black eye, white kidney, chickpeas, sesame and millet.

Smith and Stroshine (1985) found that the pneumatic separation of corn cobs from stalks is complex, because the terminal velocities of some stalks overlapped with those of the cobs. Uhl and Lamp (1966) reported that approximately 94% of wheat straw could be removed from the grain without grain loss under an air stream. Tado *et al*. (1999) found that the mean terminal velocity of paddy rice increased with the increase in moisture content.

Yahaya (1999) investigating the aerodynamic properties of the small root crops found the terminal velocities of tiger nut (*Cyperus esculentus*), flowering bulbs (Gladiolus - *Iridaceae gladius*), and onion sets (*Allium cepa* L.) up to 8.4, 22.0 and 24.0 m s^{-1}, respectively. El-Awady and El-Sayed (1994) investigated the aerodynamic separation of the product components of the shelled peanut. They found that the air separation of unshelled, split and intact seed components from the shells is difficult due to the interference of the terminal velocity of the components.

The aim of this work is to record preliminary information on the dimensions and aerodynamic properties of the peanut in order to develop a suitable separation device able to separate seeds from shells with the minimum of loss.

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THEORETICAL BACKGROUND

It is well known that the indexes characterizing the behaviour of a particle in an air stream are its terminal velocity v_t, coefficient of drag c_d, and the coefficient of the air resistance c_a.

A particle under a vertical airflow, gravitational force F_g and drag resistance force F_d act on the particle as expressed in the following formulas after integration:

$$F_d = c_a \rho_a A \, (v_a - u)^2 \,, \tag{1}$$

where ρ_a - specific density of air, kg m^{-3}; A - projected particle surface area, m^2; v_a - velocity of airflow, m s^{-1}; u - velocity of the displacement of the particle, m s^{-1}; and $v_a - u = v_t$ - relative velocity between airflow and the particle.

Under vertical airflow, the forces F_g and F_d are oppositely directed. Independently of the correlation of these forces, a particle will move down, if $F_g > F_d$, up, if $F_g < F_d$, in equilibrium if $F_g = F_d$ when $u = 0$, thus:

$$v_t = (F_g / c_a \rho_a A)^{1/2}. \tag{2}$$

The terminal velocity of irregularly shaped particles is not constant, because of their movement in the airflow. The terminal velocity for spherical and non-spherical particles is expressed by Bezrutskin *et al.* (1967), respectively, as:

$$v_t = \left(4 g \gamma_m d / 3 c_a \rho_a\right)^{1/2} \tag{3}$$

and

$$v_t = \left(g \gamma_m d_g / c_a \rho_a\right)^{1/2}, \tag{4}$$

where: γ_m - specific mass density of the crop, kg m^{-3}; d - diameter of the crop particle, mm; and d_g - geometric diameter, mm.

The values of the coefficients c_d and c_a are firmly in a complex relationship with the dimensions of the crops, state of the area of the crop and the relative velocity between air and the crop.

For these reasons, the terminal velocity will be defined only experimentally; the coefficients c_d and c_a are defined by Bezrutskin *et al.* (1967), as:

$$c_d = g / v_t^2 , \tag{5}$$

$$c_a = c_d \, m / \rho_a A \,, \tag{6}$$

where: g - gravitational acceleration, m s^{-2}; ρ_a - specific density of air, kg m^{-3}; and m - mass of particle, kg.

MATERIALS AND METHODS

Experiments were carried out on three peanut varieties (American, Chinese, and Egyptian), to predict the preliminary aerodynamic properties of these species at harvesting (peanut pods separation from soil and crop residues) for a further post-harvesting process (shelling). The Egyptian variety (Gisa-5) was brought from the Agricultural Research Station in Ismailia, Egypt, and the two other varieties were furnished by the Institute for Agricultural Engineering of the University of Hohenheim, Germany, where experiments were conducted.

To carry out research on the separation process of the Egyptian variety, the pods of this variety were shelled. The components obtained from the shelled peanut pods by using a shaker apparatus are: intact seeds, split seeds, and shells with three sieving meshes (12.5, 8.0, and 6.3 mm).

A sieving mesh of 12.5 mm was used to separate only big shells and unshelled pods from the shelled components, while meshes of 8.0 and 6.3 mm were used to separate the mixture of intact and split seeds, and small shells. Because this was an experimental process, it was performed manually.

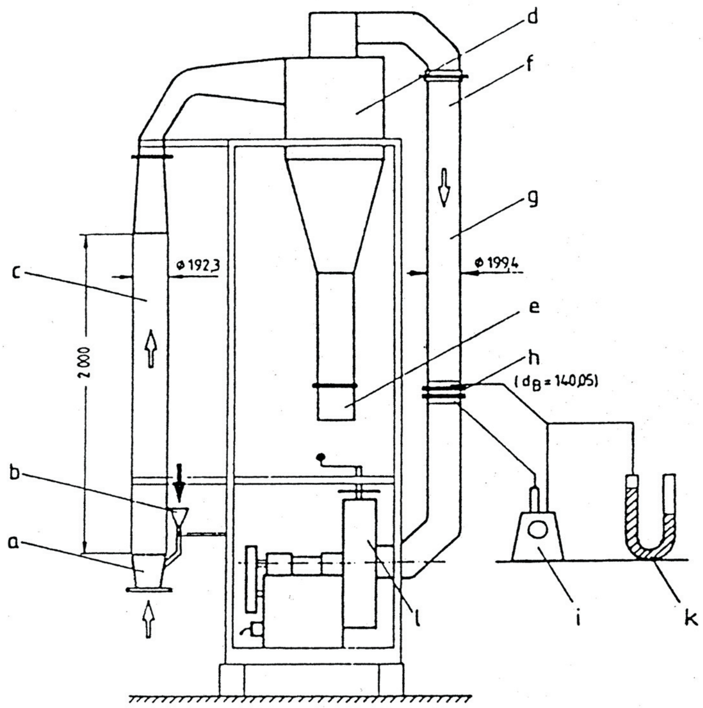
A sample of 100 particles for each peanut component was taken randomly to measure their dimensions (length - L, width - W, and thickness - T) with dial calipers and masses with a sensitive balance with an accuracy of 0.05 mm and 0.001 g, respectively. The geometric diameter was calculated as: $d_g = \sqrt[3]{L \cdot W \cdot T}$.

Terminal velocity measurement

The terminal velocity was measured using a test stand as shown schematically in Fig. 1. It consists of a vertical transparent (plexi-glass) tube, 2 m long with a diameter of 192.3 mm, which was used to suspend the particles in an air stream. The air was supplied by a suction blower fan powered by an electric motor. The air pressure delivered from the fan was aspired via a pipe to the orifice plate through a throttle. The mean air velocity in the suspension tube was obtained from calibration tests using a pitot tube and a manometer. The test stand was calibrated so that the air velocity in the suspension tube could be directly recorded from the water pressure readings on the manometer.

To investigate the aerodynamic characteristics of the peanut, three pod varieties and shelled components of the Egyptian variety were defined. The test was carried out by placing the sample weighed into the transparent (plexi-glass) tube through the feeding funnel (b). The fan discharge was increased manually until the particles seen through the transparent tube were carried to the outlet (e) through the cyclone (d). After a period of time, the remaining material in the pipe nozzle (a) where air is introduced, was weighed on an electronic scale and registered. The operation was continued until no particle remained on the surface of the pipe nozzle.

The accuracy of the measurement is influenced by suspension time and the amount of material. Therefore weights of 25, 65, 100, and 200 g was used for samples for peanut pods, shells, intact and split seeds, respectively. A suspension time at each step of 5 min was kept constant for all experiments. All experiments were replicated three times.



a - Pipe nozzle
b - Feeding funnel
c - Transparent suspension tube
d - Cyclone
e - Outlet
f - Electric rectifier with perforated disc after VDI 2040
g - Piping to the orifice plate
h - Orifice plate according to DIN 1952
i - Betz manometer
k - Water manometer
l - Radial flow compressor with throttle

Fig. 1. Test stand for the measurement of the terminal velocity of bulk materials (Institute for Agricultural Engineering, University of Hohenheim, Germany).

RESULTS AND DISCUSSION

Physical properties

Some physical properties of three peanut varieties such as the length, width, thickness and mass were measured. The mean values of the dimensions of these varieties as well as their geometric diameter and standard deviation are presented in Table 1. The Egyptian variety has the lowest geometric diameter and mass values however, it has the highest mean value of length.

A comparison of the mean values for the three varieties showed the following range of geometric diameter 21.05, 20.59, and 20.34 mm and 2.21, 2.17, and 2.13 g of mass, for the Chinese, American, and Egyptian varieties, respectively. The standard deviations of geometric diameter and mass of the three varieties showed no significant differences.

To obtain a seed classification, the dimensions and masses of seeds were investigated after using two sieve dimensions (8.0 and 6.3 mm). Table 2 shows that large dimensions and masses of intact seeds were obtained on a sieve surface of 8.0 mm, and small dimensions of intact seeds on a sieve surface of 6.3 mm. The geometric diameter and mass values of the intact seeds were found to be up to 11.73 mm and 0.89 g on a sieve surface of 8.0 mm, while these values were 8.83 mm and 0.40 g on a sieve surface of 6.3 mm.

Aerodynamic properties

The terminal velocities of peanuts and shelled components in a vertical air stream were measured, and the velocity curves of the peanut pods are shown in Fig. 2. Little variation was evident among the different varieties under study. The average value of the terminal velocities was found to be up to 10.9, 11.1, and 11.4 m s^{-1} for the Egyptian, American, and Chinese varieties, respectively. In general, the terminal velocity for the different varieties of pods ranged between 7.7 to 12.9 m s^{-1}. Hence, these values could be taken into consideration when developing devices for the separation of peanut parts. To remove lighter material from the peanut pods by an air stream, the velocity of airflow may not exceed 7.7 m s^{-1}. Meanwhile, to separate peanut pods from the heavier material, the airflow velocity may not be less than 12.9 m s^{-1} to achieve minimum pod loss.

The shelled component velocities under surfaces of sieves of different sizes for the Egyptian peanut variety are presented in Figs 3-5.

During the separation process, the shells should be separated from seeds mechanically or pneumatically. The average value of the terminal velocities of shells was found to be 3.1, 3.5 and 4.1 m s^{-1} on sieve surfaces of 6.3, 8.0, and 12.5 mm, respectively.

Table 1. Dimensions and masses of peanut pods for the three varieties

Dimensions	American	Chinese	Egyptian
Length, *L* (mm):			
Range	29.40 - 44.20	28.10 - 45.10	30.15 - 47.40
Mean value	35.86	36.03	38.76
STD	2.93	3.29	3.04
Width, *W* (mm):			
Range	12.65 - 20.35	13.6 - 36.3	11.2 - 16.65
Mean value	14.96	17.01	14.06
STD	1.12	2.24	1.02
Thickness, *T* (mm):			
Range	12.60 - 19.25	12.25 - 18.60	12.10 - 19.20
Mean value	16.34	15.32	15.49
STD	1.39	1.00	1.11
Geometric diameter, d_g (mm):			
Range	17.66 - 24.21	18.10 - 27.01	16.49 - 23.58
Mean value	20.59	21.05	20.34
STD	1.23	1.35	1.19
Mass, *m* (g):			
Range	1.06 - 3.60	1.14 - 3.21	0.66 - 3.01
Mean value	2.17	2.21	2.13
STD	0.50	0.46	0.49

Table 2. Dimensions and masses of intact and split seeds for an Egyptian variety on two sieve sizes

Dimensions	8.0 mm		6.3 mm	
	Intact seeds	Split seeds	Intact seeds	Split seeds
Length, *L* (mm):				
Range	16.35 - 24.85	15.05 - 22.10	12.60 - 19.35	14.50 - 21.80
Mean value	19.53	18.58	16.11	18.03
STD	1.48	1.58	1.65	1.62
Width, *W* (mm):				
Range	7.45 - 11.25	7.5 - 10.25	5.35 - 9.20	6.85 - 9.30
Mean value	9.72	9.00	6.88	7.92
STD	0.84	0.63	0.75	0.53
Thickness, *T* (mm):				
Range	6.65 - 10.80	3.05 - 7.40	4.40 - 7.85	3.05 - 6.75
Mean value	8.53	5.32	6.24	4.73
STD	0.74	0.71	0.71	0.68
Geometric diameter, d_g (mm):				
Range	9.36 - 13.77	7.42 - 11.33	7.19 - 10.63	6.84 - 10.46
Mean value	11.73	9.59	8.83	8.75
STD	0.76	0.63	0.81	0.65
Mass, *m* (g):				
Range	0.48 - 1.17	0.32 - 0.68	0.21 - 0.72	0.19 - 0.53
Mean value	0.89	0.49	0.40	0.38
STD	0.15	0.06	0.10	0.06

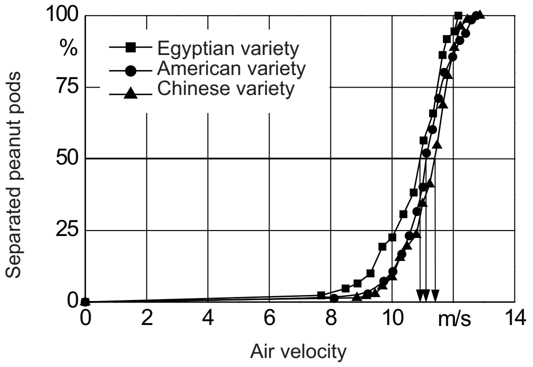


Fig. 2. Terminal velocity curves of peanut pods for three varieties.

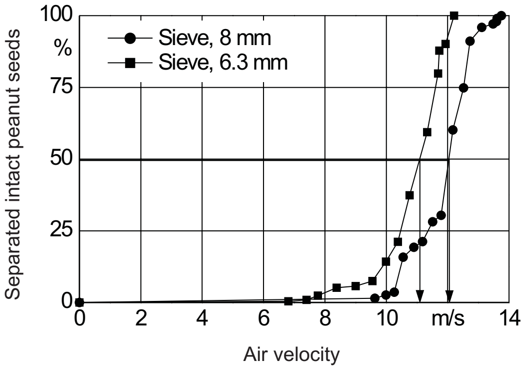


Fig. 4. Terminal velocity of intact seeds.

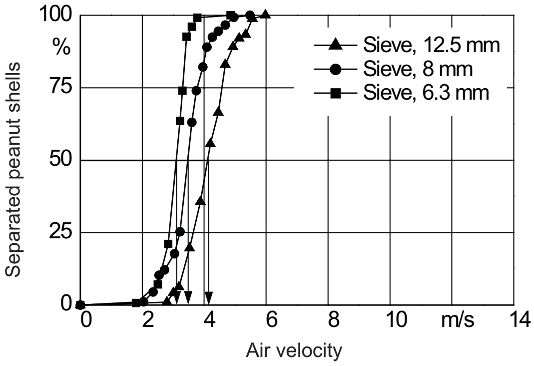


Fig. 3. Terminal velocity curves of peanut shells.

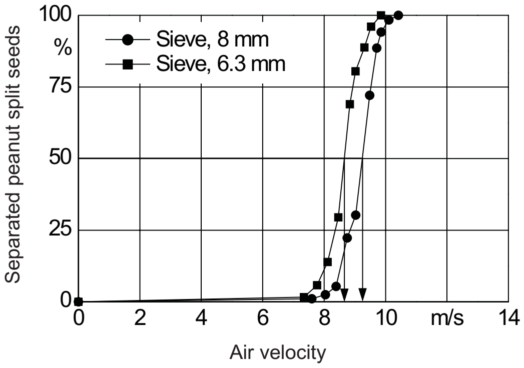


Fig. 5. Terminal velocity of split seeds.

Figure 3 shows that under surfaces of sieves with mesh sizes of 6.3 mm, the terminal velocity value of 3.8 m s^{-1} removed 99.1% of shells. This velocity value removed 5.4% of the medium shells on a sieve surface of 8.0 mm but only 31.2% of large shells on a sieve surface of 12.5 mm.

An airflow velocity value of 5.0 m s^{-1} removed 99.4% of the shells on a sieve surface of 8.0 mm, while 100% were removed on a sieve surface of 6.3 mm and 90.6% were removed on a sieve surface of 12.5 mm. Meanwhile, an airflow velocity value of 5.9 m s^{-1} was found to remove 100% of the shells on a sieve surface of 12.5 mm.

Combining the three shells dimensions, the results show that an airflow velocity value of 5.9 m s^{-1} is sufficient to remove all shells from the peanut seeds without loss.

Intact seeds are the main components obtainable at the end of a separation process. The cumulative curves in Fig. 4 showed a mean terminal velocity value of 11.1 and 12.0 m s^{-1} after sieving through meshes of 6.3 and 8.0 mm, respectively. Hence, for both seeds on sieves of 8.0 and 6.3 mm, an airflow velocity value of 7.4 m s^{-1} occurs with a 1.8% seed loss. A velocity value of 12.2 m s^{-1} removes 99.4 and 61.2% of intact seeds on sieves of 6.3 and 8.0 mm, respectively, while 13.6 m s^{-1} removes 99.4 and 100% of intact seeds on sieves of 8.0 and 6.3 mm, respectively.

The experimental measurements showed a terminal velocity average value of 8.7 and 9.2 m s^{-1} for the split seeds on sieves of 6.3 and 8.0 mm, respectively, as shown in Fig. 5. The air velocity value of 7.3 m s^{-1} occurs with a loss of 2.3 and 0.9% of split seeds, while 9.8 m s^{-1} removes 99.4 and 94.0% on sieves of 6.3 and 8.0 mm, respectively. Also an air velocity value of 10.2 m s^{-1} removes 99.5 and 100% of split seeds on sieves of 8.0 and 6.3 mm, respectively. It seems from the results obtained that the air velocity values of 10.2 and 9.8 m s^{-1} are adequate to separate the split seeds from the intact seeds as these values remove 99.5 and 99.4% of split seeds on sieves of 8.0 and 6.3 mm, respectively.

CONCLUSION

In conclusion, the terminal velocity value of peanut shells is lower than that obtained from seeds. The value of 7.4 m s^{-1} was found to be the optimum airflow velocity in order to separate the shelled Egyptian peanut components from the shells with only a 1.8% loss of intact and split seeds, and airflow velocity values of 10.2 and 9.8 m s^{-1} are adequate to separate split seeds from intact seeds when they are sieved on surfaces with meshes of 8.0 and 6.3 mm, respectively.

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NOTATIONS

A - projected particle surface area (m^2)
c_a - coefficient of the air resistance
c_d - coefficient of drag
d - diameter of the crop particle (mm)
d_g - geometric diameter (mm)
F_d - drag resistance force (N)
F_g - gravitational force (N)
g - gravitational acceleration (m s^{-2})
L - length of particle (mm)
T - thickness of particle (mm)
m - mass of particle (kg)
u - velocity of the displacement of the particle (m s^{-1})
v_a - velocity of airflow (m s^{-1})
v_t - terminal velocity (m s^{-1})
W - width of particle (mm)
γ_m - specific mass density of the crop (kg m^{-3})
ρ_a - specific density of air (kg m^{-3})